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Worldwide Report

NUCLEAR DEVELOPMENT AND PROLIFERATION

No. 57

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CONTENTS

CRITICISM OF NUCLEAR WASTE DUMPING PLANS REPORTED

Tokyo KYODO in English no time given 19 Jul 80

[Text] Saipan July 19 KYODO--Japan's plan to dump radioactive waste from its nuclear power plants into the Central Pacific has drawn sharp criticism from island residents in the area.

The Northern Marianas Commonwealth Legislature, for example, is ready to call on fellow island countries in the Pacific to join it in refusing to sign new fishery agreements with Japan if the Tokyo government does not give up the plan.

Under the plan, Japan would dispose of about 2 million liters of radioactive waste in waters some 900 kilometers southeast of Tokyo starting next summer.

The major island of Saipan, located in the center of the Marianas, is about 2,500 kilometers south of the Japanese capital.

Joaquin Pangelinan, speaker of the House of Representatives of the Commonwealth Legislature, said he is opposed to radioactive waste disposing by any countries.

Why doesn't the Japanese government, Pangelinan asked, dump the industrial waste in its own territory if it is really safe and low in radioactivity.

How would the Japanese feel if the Russians say they plan to throw away radioactive materials near the northern island of Hokkaido, he added.

Lt Gov Joseph F. Ada of Guam echoed Pangelinan by saying that Japan should scrap the plan so it won't create a health hazard to the future generations of the Pacific basin.

Ada reminded the Japanese that tuna and bonito, their favorites commonly taken raw, may be contaminated by the industrial waste.

The Commonwealth Legislature has also decided to send delegates to Tokyo to request the government to scrap the waste disposal plan.

The islanders' visit to Japan in August coincides with the 35th anniversary of the atomic bombings in Hiroshima and Nagasaki, according to officials of the Legislature.

CSO: 5100

PROCESS FOR RADIOACTIVE WASTE DISPOSAL DESCRIBED

Budapest ENERGIA ES ATOMTECHNIKA in Hungarian Vol 33 No 1, Jan 80 pp 29-39

[Article by Miklos Magyar, Gyula Mozes, and Mihaly Kristof, Hungarian Research Institute for Petroleum and Natural Gas (MAFKI)]

[Excerpts] Our institute, MAFKI, has studied the disposal of liquid radioactive materials of low and medium activity, capable of harming the environment, with the aid of bitumens.

In this article we discuss only the disposal of liquid wastes.

Three processes (concentration, embedding, and packaging) are usually performed together, and since the characteristic feature of the processes is the composition and character of the embedding medium used, the processes are classified according to the embedding medium used:

a) Methods using cement
b) Methods using bitumens
c) Methods using glass
d) Other methods.

We desire to point out that the method using cement is used exclusively in the first isotope-waste storage facility in Hungary, located at the outskirts of Puspokszilagy [9].

Tests on the embedding of isotope wastes started only 10-15 years ago, and already during this period this method of disposal has experienced major development. Since the method offers a high degree of radiological safety in case of wastes having low and medium activity, and at the same time is the most economical method of solidification, it is in the center of interest today [10].

The current interest in these studies is also evident from the fact that the CEMA committee on the peaceful uses of nuclear energy has developed a coordinated study plan on disposal with bitumen for the CEMA member countries. Scientific consultations and reports by the various institutions within the framework of this project have contributed significantly to a fast advancement of the subject matter [23].

An important goal of the studies is to increase the specific quantity of material that can be embedded into the bitumen, in the solid form, since this parameter affects the economy of the process. For a given waste and given technological conditions, the amount that can be embedded has a limit value beyond which any further addition of waste will result in major increase in leachability. Insofar as this limit value is concerned, the opinions still differ; however, it is certain that the distribution homogeneity of the embedded material plays an important role in this connection. For a given waste, this is closely related to the technological parameters of the embedding process.

Table 1 [the table and the graphics are at the end of the translation] summarizes the characteristic features of the equipment proposed by the CEMA countries. The table provides a clear picture of the status of the relevant research and development work in these countries [23].

It should be mentioned here that Hungarian researchers [28] have investigated the possibility of the concentration of radioactive wastes from nuclear power plants below the boiling point to the solid salt state. These studies have been in progress for a long time.

3. The bitumen method developed in our institute for the disposal of radioactive wastes

We have mentioned earlier that many technologies have been developed during the early 1960's for the embedding of the unavoidable isotope wastes which were generated as the nuclear power plants started to proliferate in bitumen. The sole disadvantage of the use of bitumens was that fires and even explosions occurred frequently in the process equipment (which was of the open type with internal heating), primarily in cases where the solutions contained much nitrite and nitrate which formed in the course of the regeneration of the fuel elements of the nuclear reactors. It has also often happened that that the waste:bitumen ratio employed in these technologies was wrong, so that the waste did not incorporate properly in the micelles of the bitumen.

Aware of these difficulties, we started the studies—commissioned by the International Atomic Energy Agency (IAEA) and the NIM [Ministry of Heavy Industry]— which ultimately resulted in the development of a novel process and technology [24, 25, 26].

Our basic concept was to embed the salt content of radioactive solutions into bitumen at a relatively low temperature in a single technological step.

We heated the bitumen in a reactor with a relatively small cross section, using electrical heating, to 160-180°C. The bitumen was stirred with inert gas (nitrogen) injected at the bottom of the reactor. The salt-containing solution of slurry was fed onto the top of the bitumen slowly. The water content of the solution or slurry evaporated on the surface of the bitumen and the salt became embedded in the bitumen in a finely distributed form.

The following are the advantages of this approach over the conventional technologies:

- The heat transfer is more favorable in the reactor with relatively small cross section, and the stirring with gas improves it further via internal diffusion.

- A fully closed system can be devised; the nitrogen atmosphere eliminates the hazards of ignition and explosion.

- Since it is a one-step technology, i.e., the solutions or slurries are fed onto the top surface of the bitumen together with their water content, the process is elastic, its parameters can be easily modified as a function of the salt or solid-matter concentration.

- The water reaching the surface of the hot bitumen forms a large-surface foam phase which on the one hand retains or at least reduces the impurities entrained by the gas or steam flow, and on the other hand ensures that the solid-matter content of the solution or the slurry is distributed uniformly and finely in the bitumen.

On the basis of the preliminary laboratory experiments we designed a pilot-plant experimental facility operating in steps. After we have evaluated and improved this facility, we constructed a small industrial-scale facility which operated with a continuous technology.

In the course of the development of the continuous technology and the construction of the new facility we solved additional problems. Among others,

we solved the problem of nitrogen recirculation, of regulating the bitumen level during the continuous process, of feeding the bitumen continuously, of removing the condensate continuously, and of ensuring that the reactor-service systems operate properly. These solutions contributed to the realization of the continuous embedding technology [29, 30].

3.1. The continuous bitumenization equipment

Figure 1 illustrates the principle of our continuous process. We retained the 100 mm long reactor with an internal diameter of 120 mm, which operates stepwise, but to increase the capacity we added a conical section above the reactor to increase the foam space. In this manner we achieved that the amount of bitumen that can be added increased to 30 kg, and that the enlarged foam space (evaporation surface) permitted the evaporation of seven liters of solution or water per hour on the average. We devised a fan-cooled condenser, of vertical design with ribbed structure and trickling, to permit the condensation of the increased amount of water. The condensate collected in the separator tank under the condenser; the inert gas was fed back at the bottom of the reactor after having passed through a droplet trap and the compressor's buffer tank. The bitumen was fed to the reactor from the preheater by a pump. The drawing also shows the pneumatic dispenser controlled by a pulse generator, the pressure-measuring and -regulating unit, the thermometers, and the level-control instruments.

The apparatus operated continuously in the following manner: The bitumen fed to the preheater was heated to 160-180°C by an electric heater to melt it. The reactor and the feed lines were preheated to approximately 150-160°C, and the circulation of the nitrogen was started from the nitrogen tank at a gauge pressure of 2.5 atm. The reactor was charged with bitumen and the feeding of the salt-containing solution started. Once the pressure in the reactor reached 0.1-0.2 atm (gauge pressure), the cooler and condenser fan was started. The reactor was operated batchwise until the specified salt concentration was reached, and then the gradual feeding of the bitumen and the removal of the salt-containing bitumen was started. The removal rate of the bitumen was regulated by a metering unit controlled by a pneumatic pulse generator. The process was shut down in the same steps in reverse sequence.

3.2. The quality of bitumens used for embedding

In the course of our study we evaluated 12 bitumens of Hungarian manufacture, coming from various sources and made in various ways.

Of these bitumens three originated from the USSR (made of petroleum from Romaskino, supplied via a pipeline) and the others originated from Nagylengyel.

We carried out batchwise embedding tests with all 12 bitumens, using the following constant parameters:

- Amount of bitumen: 12 kg
- Reactor temperature: 200°C
- Rate of solution or slurry feeding: 0.5 liters per hour
- Duration of the test: Five hours

The salt content in the aqueous slurry used for the experiment was 37 percent by weight. The salt consisted of 75 percent by weight of sodium nitrate, 16 percent by weight of sodium hydroxide, 5 percent by weight of aluminum chloride, and 4 percent by weight of sodium sulfate. After completion of the feeding of the solution or slurry, we stirred the bitumen-salt mixtures in the reactor with nitrogen for 30 minutes, and after it was drained we determined the physical properties—salt content, salt distribution, softening point, salt leachability, and dry-matter content of the distillate—of the mixtures. We selected the bitumens on the basis of the measured values [29, 30].

The studies indicated that bitumens having a softening point of more than 70°C do not incorporate the solid matter properly in their structure, so that they can be leached out relatively easily. Bitumens having a lower softening point incorporate the solid matter properly in their structure, meaning that they are satisfactory insofar as leachability is concerned; however, a small portion of their so-called oil content enters the condensate. Oxidized (blown) bitumens with a higher softening point have a high viscosity after saturation with salt; they are also flammable. Accordingly, they cannot be considered for use. Table 2 shows the properties of those bitumens which we judged suitable for the intended purpose.

From the bitumens listed in Table 2 we prepared bitumen-salt mixtures of various compositions and admixture ratios in such a manner that we left out one component at a time of the salt mixtures used in the individual experiments, and added the remaining components to the bitumen in the same ratio as they were contained in the original slurry. We maintained the mixtures at 200°C for six hours, and then examined the extent to which the "asphaltene + salt" content selected as the basic-component group became enriched as a result of this heat treatment. We found that significant chemical reaction takes place only in the presence of sodium nitrate

but that even in this case the reaction takes place at a very slow rate in the 160°C - 180°C temperature range.

The results of our further experiments indicated that minimum "oil distillate" is evident with the bitumens UB-45 and NB-30, while both bitumens fully incorporate the solid-matter content of the slurry. The bitumen R-III yields somewhat more distillate and shows minimum salt segregation in the salt-concentration range of 25-30 percent by weight. For all practical purposes, no oil is distilled off the bitumen M-60; however, this bitumen does not incorporate the salt as well into its structure as the others: there is significant salt segregation from an embedded salt concentration of 20 percent by weight onward.

We may sum up the result of our experiments by stating that from among the bitumen types tested those identified UB-45 and NB-30 are best suited for the intended purpose.

3.3. Leaching studies

We subjected the bitumens containing various amounts of salt, generated in the experiments, to leaching tests [29].

For the tests we dissolved a few grams of bitumen or salt-containing bitumen in n-hexane, and determined the so-called asphaltene content and the total asphaltene and salt content. We cast samples from the salt-containing bitumens—which we knew precisely and which conformed to the plans—in stainles-steel rings having a height of 5 mm and an internal diameter of 25 mm, cut their top flush with a hot knife, placed them in 50 ml portions of distilled water, and kept tham for three months sealed at room temperature. We also carried out the tests with tap water (approximately 21-24 degrees German hardness). After the prescribed period has elapsed, we removed the samples from the water, evaporated the solution to dryness, and determined the so-called leached-out salt content.

We found no difference between distilled water and tap water insofar asthe leached-out salt content was concerned. The results obtained for the bitumen NB-30 are shown in Fig. 2. It can be seen that the amount of leached-out salt increases (related to the total salt content) if the total salt incorporated in the bitumen is increased. This rate of increase became particularly pronounced from a 30 percent by weight total salt content onward. The bitumens UB-45, R-III, and M-60 gave similar results. The major increase of leaching above a total salt content of 30 percent by weight is obviously the consequence of the inhomogeneous distribution of the salt content. This is supported by the observation that salt segregation and

salt sedimentation started after more than 30 percent by weight of salt was incorporated, although its extent varied for the various bitumen types.

On the basis of the foregoing, we conclude that the maximum salt content must not exceed 30 percent by weight in bitumen embedding processes—for both technological and stability reasons.

4. Preparation of report and proposal for the treatment, shipment, and storage of liquid isotope wastes from the nuclear power plant in Paks

An important task of the Paks Nuclear Power Plant Enterprise (PAV) is the long-term solution for the decontamination, storage, and disposal of the liquid radioactive wastes generated after the plant has been started up. The PAV commissioned our institute, among others, to study this matter and to prepare a report and a proposal for a solution.

Before describing the research and development activities carried out in our institute over the last two years, we mention the well-known fact that the development of an industrial-scale technology generally takes place in three phases. These phases are the following:

a) Basic studies concerning the development of the technology, principles and equipment;

b) Construction of a pilot plant and its operation to establish the optimum technological parameters to guide in the designing of the full-scale facility;

c) Design and construction of the industrial-scale facility realizing the specific industrial goal; startup and adjustment of the system.

It is evident from the foregoing that our institute is now past the first two stages as a result of its research and development activities concerning the disposal of radioactive waste with bitumen. At the beginning of Section 3 we mentioned the fact that our initial experiments and measurements were carried out in laboratory equipment and also in pilot-plant equipment operated on a batchwise basis. We solved our basic research problems with these reactors [31]. We examined the changes in the chemical and physicochemical properties of the materials fed into the process as the process progressed. We established the thermochemical and reaction-kinetic fundamental data, and on the basis of these data elucidated the chemical reactor-engineering relationships. Now that we knew the transport phenomena, we were in a position to create the mathematical model of the operating unit [32].

In the second phase of the project—as we have described—we upscaled the earlier reactor (a capacity of 7 liters per hour) and made the process continuous. In this connection it should be noted that the "pilot-plant" capacity obtained in this manner sufficed for the specific domestic needs of the time. At the time, the annual amount of liquid isotope waste generated in the country was a mere 3-5 cubic meters.

Execution of the commission from the PAV represented the third phase of the project. First, on the basis of the data supplied by the PAV, we had to adapt our process to the conditions of Paks—involving the concentration, decontamination, and disposal of considerably more liquid waste in a satisfactory manner from 1980 onward— second, we had to design the concentrating, bituminizing, storage, shipping, and "burying" facilities to a degree that they conform to the standards for bids [33,34,36].

To ensure the proper competence for the solution of the problems involved, we contracted with subcontractors for specific aspects of the project. These subcontractors included the Isotope Institute of the MTA [Hungarian Academy of Sciences], the Hungarian State Institute of Geology, the Radioactive Waste Processing and Storing Section (RHFT) in Puspokszilagy of the Capital-City Public-Health and Epidemiology Station in Budapest, and the Research Institute for Chemical Technology of the MTA.

4.1. Development of the Embedding Equipment for Processing 100 kp Per Hour Liquid Waste

Retaining the principle of our process, as described above, and making use of a patent application of the Research Institute for Chemical Technology of the MTA [35], we developed, in cooperation with this institute, a rotating reactor which performs the evaporation of the radioactive salt solution (suspension) and also the embedding of the solid-matter content in bitumen, meaning that both processes can be carried out in the same equipment. The internal design and specific heater surface of the continuously operating embedding unit are such that its processing capacity is high for its size, and that it represents a closed system. The system, consisting of the embedding apparatus and its auxiliary devices, produces a product containing 30 percent of salt by weight, wherein the salts are distributed finely and resist leaching by water. The condensate emerging from the system may be fed back to the unit if its activity permits this—via decontaminating and activated-carbon filtration if necessary. Only negligible amounts of gas escape from the system. The system is elastic, and creates no fire or explosion hazard in operation.

4.2. Development of the Technology for Processing 100 kg of Waste Per Hour

Figure 3 shows the block diagram of the embedding technology designed for the processing of 1,200 cubic meters of solution (suspension) containing 200 grams of salt per liter within an operating period of 3,600 hours. Table 3 shows the characteristics of the (bitumen + salt) product obtained.

Of course, an integral part of the technology is the packaging of the product, as it emerges from the "product collector," into containers for shipping. We therefore dealt with this subject too, and developed the principle of a mechanism that fills the sheet-steel drums, seals the drums, and "moves the drums stepwise." We also established the mechanical-engineering parameters of the device to permit final construction plans to be prepared.

4.3. Preliminary Plan of the Waste-Embedding Plant

We prepared a preliminary plan for the four operational units of the system for embedding 1,200 cubic meters of salt solution during 3,600 hours of operation, the auxiliary facilities for this system, a temporary storage facility for the packaged products, and the waste-processing building with five levels made of monolithic steel-reinforced concrete walls and roof. We determined the principal dimensions and the outline of the interiors for the intended purpose.

4.4. Studies on the Shipping and Final Disposal of the Embedded Waste

Matters concerning the storage and shipment of solidified radioactive waste are still unresolved in some aspects, or are controversial, even in countries with highly developed nuclear industry. The ultimate separation of the liquid radioactive wastes from the environment is generally accomplished according to the following scheme.

a) In most instances the liquid and solid wastes are solidified and packaged at the nuclear power plant site. They are shipped in the form they are generated only under exceptional circumstances.

b) The solidified and packaged wastes are stored on the site until a lot for shipping accumulates. The solutions used for this include outdoor dumps (if the waste is properly solidified and packaged), light-structure storage buildings, underground concrete tanks, and concrete tunnels.

c) To transport the waste to the ultimate storage facility, open-platform trucks or various protected vehicles are used. They travel on public highways and must conform to the national regulations.

d) At the ultimate storage site, the solidified and packaged wastes are deposited in abandoned mines or subterranean artificial depositories. The depositories are insulated from the environment in a suitable manner. Until such time that domestic regulations are promulgated for the shipment and storage of embedded isotope wastes, we developed a proposal for the shipment and storage of the wastes generated by the PAV, using as the basis the expected composition and quantity from the PAV, the character of the embedded product obtained from our system, and available domestic and foreign experience.

Cooperating with the Isotope Institute of the MTA, we established that the leaching of the isotopes embedded in bitumen according to our method with water and diluted hydrochloric acid is not significant. We also established that the bitumens irradiated with the gamma rays of the Co-60 isotope, calculated from the internal dose corresponding to a storage time of 600 years, generate only minimum quantities of gaseous products, and that the gas pressure above the bitumen can increase by no more than 0.2 atm (gauge pressure) per year if the drums are properly sealed. Thus, the studies indicate that the low-level solid radioactive product obtained from our process may be shipped in suitable industrial packages, for example in well-sealed metal drums, as a "full load" around which the dose rate is permissible at a distance of 10 meters.

Our studies and analyses indicated that the RHFT site in Puspokszilagy, operated by the KOJAL [Public Health and Medical Clinic for Contagious Diseases] of the capital city would be suitable as a depository for the final storage of the waste embedded in bitumen according to our method and packaged in sheet-iron drums, provided that the required auxiliary investments are provided. On the basis of geological considerations it is also likely that a storage site could be developed in the area of Hidas, Kismoragy, Feked, and Sarszentmiklos for the final disposal of the PAV wastes. Each of these solutions has its advantages and disadvantages. They were analyzed in detail, and the results of our analysis would permit the authorities in charge to render a final decision, provided that any required additional studies are carried out.

4.5. The Tasks Still Ahead

In conclusion we stress that in our opinion the solidification, packaging, and ultimate disposal of the liquid isotope wastes generated at the PAV

must be regarded as a system—as the foregoing brief summary also indicates—of which each individual element is closely related to the other elements and interacts with same. Accordingly, a prerequisite for the economical and fully safe operation of the system is that each and every element of the system reacts elastically and quickly to changes that take place while the system is in operation.

In view of this, we developed a plan for the details of the tasks still to be carried out during the next 1-2 years in connection with our embedding technology, the temporary storage of the (bitumen + salt) product, shipping and final disposal of the waste, and final design and construction plans. An evaluation of these tasks and in view of the international situation in this respect we believe that the research/development group that formed from several institutions in Hungary can develop satisfactory solutions under the supervision of the PAV and with the help of an appropriate design institute. We still have sufficient time to solve with domestically available resources the still outstanding problems concerning the solidification of the expected waste from the PAV, the shipment of the solidified waste, and the final disposal, provided that we start soon.

In conclusion, we are pleased to extend our thanks to Dr. Aurel Ujhidy, scientific department head at the MUKKI [Research Institute of Chemical Technology]; Ferenc Golder, deputy scientific department head at the Isotope Institute of the MTA; Dr. Laszlo Feher, site-supervisor chief engineer of the KHFT, Dr. Miklos Kassai, scientific department head of the MAFI [Hungarian State Geological Institute]; and Mrs Gyorgy Hankoczy, building engineer at the VAFV [expansion unknown].

Table 1. Decontamination equipment proposed by the CEMA countries

Country	Principle of operation	Output litres/hr	Method of heating	Area heated
Bulgaria	Filtration of solution via mineral sorbents in bitumen ingots, which subsequently ensures insulation from water and moisture	5		
Hungary	Continuous operation. Mixing with waste and bitumen under stirring by bubbling nitrogen. Closed gas flow	Max. 10	Electric 18 kW	3.5 m^2*
GDR	Batchwise operation. Apparatus equipped with external heating and turbine stirrer. Bitumen emulsion.	Max. 50	Evaporation of organic heat medium 40 kW	2.5 m^2
Poland	Batchwise operation. Apparatus equipped with external heating and propeller stirring	Max. 50	Electric 30 kW	3.5 m^2
USSR	Batchwise operation, apparatus heated externally, also equipped with internal heating plugs. Propeller stirrer	Max. 70	Organic heat medium and electric 80 kW	4.8 m^2
CSSR	Continuous operation, two devices; dehydration with specially designed concentrator, bitumenization with extruder-type mixer	Max. 200	Steam	

[Table 1, continued]

Country	Bitumen type used	Waste type studied	Maximum process temp.	Solids content of product in %
Bulgaria	Battery bitumen	Diluted salt solutions (max 1 g/lit)	180°C	
Hungary	B-35	Salt solution	250°C	25
GDR	B-45	Salt solution Ion exchangers Activated carbon	230°C	Max. 50
Poland	P-60	Slurries Barium carbonate Copper sulfate Iron Potassium cyanide	340°C	20
USSR	BN-IV BN-II GUDRON BN-III BNK-II	Pan residue and slurry, as well as gas, of which the composition is the same as of nuclear power plant waste	300°C	Max. 70
USSR	BN-III BNK-II	Model mixture (pan residue and slurry) of which the composition is the same as of nuclear power plant waste	160°C	Max. 70

[Table 1, continued]

Country	Degree of readiness	Application area proposed by the authors
Bulgaria	Checked with actual wastes	For small capacity, for diluted salt solutions
Hungary	Checked with model mixtures	For units where the annual amount of waste is 10-15 m^3
GDR	Checked with pan residue. Specific activity $5 \cdot 10^{-5}$ Cu/lit	For units with a maximum capacity of 50 liters per hour
Poland	Checked with active products up to 10^{-4} Cu/lit	For units with a maximum capacity of 50 liters/hour
USSR	Checking model and with real products up to 10^{-4} Cu/lit	For units with a maximum capacity of 50 liters/hour
USSR	Checked with model mixture. The concentrator was assembled at the nuclear power plant in Novovoronezh	The concentrator must still be checked with real radioactive wastes. Preparation of the technical plan proposal for the nuclear power plant is presently in progress

[Table 1, Part 2]

Country	Principle of operation	Output lit/hr	Method of heating	Area heated
USSR	Continuous operation (batchwise if necessary); film evaporator type equipment	50, 150, 230, and 500	Steam, 22 kW at 220 lit/hr and 30 kW at 550 lit/hr	6 m^2 at 200 lit/hr 14 m^3 at 500 lit/hr
USSR	Continuous operation, two-device system for dehydration in cylindrical dryer and bitumenization in extruder	Max. 280	Organic heat carrier, electrical 300 kW	11 m^2
Czechoslovakia	Continuous operation, LUVA type film evaporator with modified bottom chamber	Max. 30	Steam 3.9 kW	1.0 m^2

* Full surface of the reactor

[Table 1, Part 2, continued]

Country	Bitumen type used	Waste type studied	Max. process temperature	Solids content of product in %
USSR	BN-I BN-II	Model mixture (pan residue and slurry), of which the composition is the same as of nuclear power plant waste	160°C	50-60
USSR	BN-III BNK-II	Pan residue and slurry from cleaners (Moscow purification station)	Drying up to 150°C; and up to 180°C	Max. 80
Czechoslovakia	Bitumen emulsion with 65% bitumen content	Salt solution of a concentration of 500 g/lit	160°C	Max. 40

[Table 1, Part 2, continued]

Country	Degree of readiness	Application area proposed by the authors
USSR	Checked with model mixture, considering all wastes of the nuclear power plant	Preparation of the engineering plan proposal for the nuclear power plant (VVER-440 and 1000, as well as RBMK reactors) is in progress
USSR	Checked under realistic conditions at the Moscow purification plant	For units operating without remote control
Czechoslovakia	Checked under realistic conditions at the purification plant of the Rzezhov nuclear power plant	For nuclear power plants operating with Type VVER-440 reactors

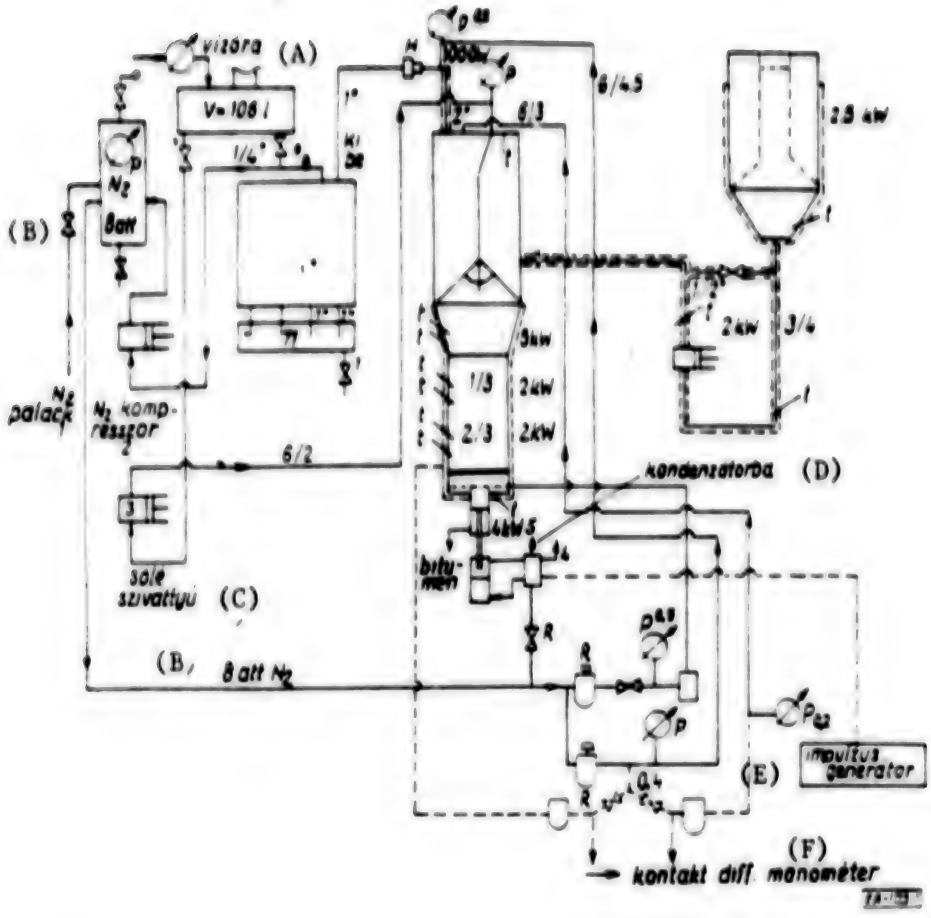

Fig. 1. Principle of the operation of the continuous apparatus.

Key:
1. Nitrogen bottle
2. Nitrogen compressor
3. Brine pump
4. Water meter
5. Condenser
6. Reactor

A. Water meter
B. 8 atm (gauge pressure)
C. Brine pump
D. To condenser
E. Pulse generator
F. Contact diff. manometer

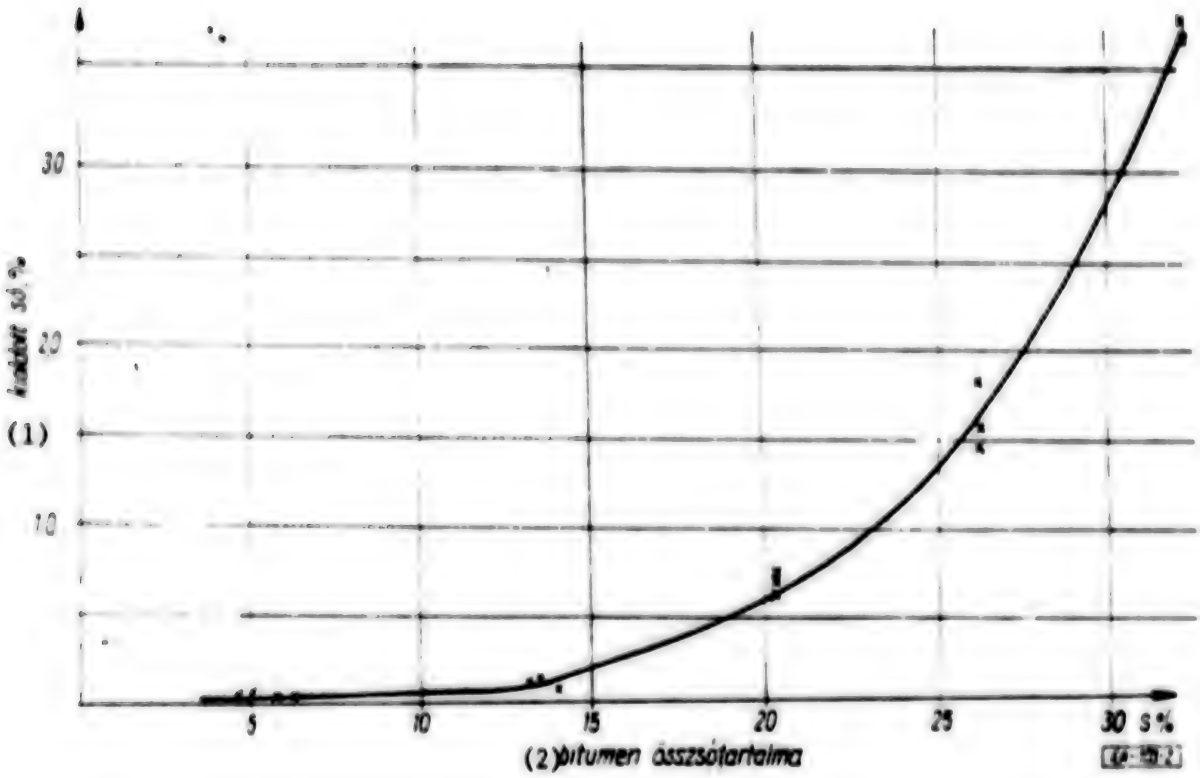

Fig. 2. Dissolution diagram of the NB-30 "salted bitumen"
Key: 1. Salt dissolved in percent
2. Total salt content of the bitumen
S% = Percent by weight

Table 2. Characteristic data of some bitumens suitable for embedding

Identification of the bitumen	Origin	Softening point in deg C	Penetration at 25°C	Breaking point deg C	Viscosity at 200°C	Explosion point in deg C
UB-45	Nagyl.dist.	40	174	-26	23.0	326
NB-30	Nagyl.dist.	70	22	-4	80.0	334
R-111	Soviet dist.	58	36	-19	37.0	307
M-60	Mexic.dist.	54	70	-14	43.1	306

Table 3. Characteristic data of the (bitumen + salt) products obtained in the tests

Test number	Salt content	0.1 mm penetration at 25°C	at 40°C	Viscosity* in cSt at 120°C	at 150°C	Softening point	Specific gravity at 20°C
R1	39.7	26	64	41,950	6,920	78	-
R2	38.2	28	77	30,860	7,920	76	-
R3	25.7	28	75	13,000	2,750	73	-
R4	28.6	25	68	16,600	3,090	74	-
R5	25.3	25	70	14,170	2,120	72	-
R6	27.3	27	78	19,030	3,420	74	-
R7	46.3	21	57	46,070	6,850	80	1.312
R8	36.1	27	65	22,180	2,670	75	-
R9	28	24	66	15,090	5,290	74	1.248

* Since the (bitumen + salt) products are viscosimetrically inhomogeneous systems in spite of the fact that the salt is uniformly distributed in them, the viscosities can be measured at an accuracy of ±20 percent only. The data shown represent the arithmetic mean of 10 individual determinations.

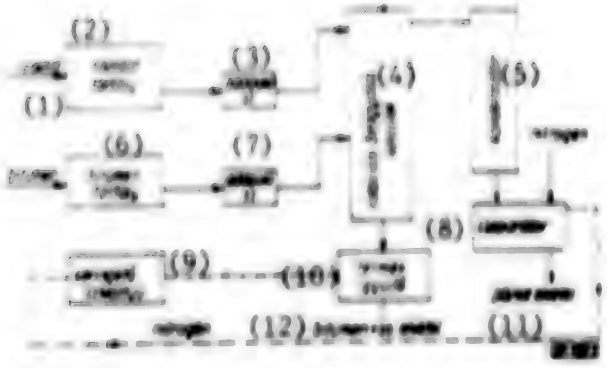

Fig. 3. The block diagram of the embedding technology

Key:
1. Salt solution
2. Salt-solution container
3. Metering pump
4. Rotary embedder
5. Condenser
6. Bitumen container
7. Metering pump
8. Separator
9. Circulating pump
10. Product collector
11. Distillate removal
12. Removal of bitumen + salt

[illegible]
CSO: 5100

ISRAEL'S NUCLEAR CAPABILITIES ANALYZED

London AL-DUSTUR in Arabic 21-27 Jul 80 pp 37-41

[Article by Muhammad 'Ali Qasim]

[Text] The assassination of Dr Yahya Amin al-Mashhad, the Arab scientist who worked in the Iraqi nuclear program, is only a link in the chain of Israel's attempts to prevent Iraq from developing its first nuclear bomb. This, of course, sheds light on the U.S. attempts to prevent the Arabs, and the Third World in general, from acquiring a defensive weapon, at the same time when Israel's nuclear knowledge is advancing. However, the question stands concerning the Israeli nuclear program, about which the Americans and the Israelis are keeping silent while raising such a clamor about the Arab nuclear program.

The question of the entrance of nuclear weapons into the arena of the Arab-Israeli struggle is by no means simply a possibility which may be realized at some future stage; the facts show almost certainly that these weapons have become actually a part of the military and strategic factors which are involved in this struggle and determine its general currents. It can still be said without much exaggerration that, during the 1980's, the nuclear factor will be a firmly established and basic part of the totality of the elements which are significant in reckoning the relationships of the forces between the Arab countries and the Israeli enemy, if not in the field of their use in the form of a direct operation, then at least on the level of the latent possession of them by one or more of the sides which are contending in the area, although it is true that a limited number of Arab countries have become increasingly conscious of the importance of this fact and of the importance of its influence on the vicissitudes of the struggle and the horizons of its future development, for the Israeli enemy was, unfortunately, first to concentrate on the importance of nuclear power, and consequently on exerting efforts toward supplying itself with it. At the time when estimates from Western sources indicate that some of the Arab programs which pertain to the development of nuclear power have reached an earnest stage which indicates increasing determination to acquire military nuclear power, these sources say, on the other hand, that Israel is at the present time the only side in the area which possesses nuclear weapons. This is something which cannot but indicate the need to emphasize the importance of the possession of such a weapon as this by the Arab nations for their own part, or at least their possession of the capability to develop it and produce it when the need calls.

The Roots of the Israeli Nuclear Program

The possession of nuclear weapons by the Israeli forces is considered the fruit of efforts which have continued for about 20 years, and it has comprised many factors of cooperation and exchange of experience between Israel and a number of Western nations. Although this cooperation was not uninterrupted, it bears an "official" character from the point of view of its being open government cooperation, for it includes in most of its stages, if not all of them, various forms and methods of direct encouragement which "some government quarters" and official intelligence apparatuses and scientific circles, which are responsible for the nuclear programs in some of the Western nations, have offered, and the constant facilitation which they provided to the Israelis in their task of developing their nuclear capabilities and bringing them to the point of actual production.

The origin of the Israeli program goes back to the late 1950's. The execution of it began at that time in the form of a program whose purpose was to develop nuclear technology to use for "peaceful purposes", especially for desalinating sea water and generating electrical power. However, the direct military goals of these efforts were too obvious to conceal. This early stage of the Israeli nuclear efforts was characterized by close cooperation with French efforts, which were going on at that time to develop independent nuclear capability for the French forces, which still lacked such a capability in comparison with the Soviet Union, the U.S.A., and Britain. What arouses concern in this field is that France followed, in the traditional manner, the principle of breaking the monopoly of the superpowers on the nuclear weapon. This principle was not represented in the attempt to obtain French capabilities alone, but goes so far as to encourage a number of chosen allies to develop their own independent nuclear forces. Of course, it is well known that Israel was at that time considered France's most favored ally, not only in the Middle East, but also throughout the Third World.

The Israeli-French cooperation bore fruit in the late 1950's and the early 1960's in the enablement of Israel to build its first nuclear reactor, the Dimona reactor, which is located in the occupied Negev Desert and which, since that time, has formed the basis of the Israeli nuclear program.

The Israelis were not contented with relying on the exchange of experience in the nuclear field with France, but set about to "penetrate" a number of other establishments belonging to various Western nations which possessed nuclear technology, even if some of these countries had not decided to use this expertise of theirs to develop their own nuclear weapons. Some Western sources say that the two most outstanding examples of that were West Germany and Canada (both of these being countries which had decided to refrain from developing nuclear weapons of their own, even though they had the capability to do so). Furthermore, the cooperation between Israel and the U.S. in the nuclear field was always a matter not to be discounted; on the contrary, it was considered probable in many circles. However, most of the guesses were that the Israeli-U.S. cooperation had not adopted an official form, but was restricted to U.S. equipment and apparatuses in which the Zionist elements possessed enough capability to enable them to carry them out beyond the stated

government policy and which calls (at least inprinciple) for restricting the spread of nuclear weapons among the small nations, even if they are allies of the U.S.

In any case, Israel has made use of this "multifaceted" policy, especially after the collapse of its political and military relations with France in the days of the regime of General de Gaulle, and a limitation following the French prohibition of the exportation of weapons to Israel after the June 1967 war. This policy at least permitted the Israelis to pursue their nuclear efforts without relying on the official French partnership. Nevertheless, all sources indicate a continuation of this partnership in secret, especially by way of the private French establishments, and bodies within the official French apparatuses which are characterized by their direct support of the Zionist entity.

Besides these assistances, the subject of direct cooperation between Israel and South Africa became prominent in the late 1960's, and the cooperation between these two parties was neither new nor strange. Nevertheless, it has tended primarily toward joint development of the nuclear capabilities since that time, while maintaining close cooperation and coordination in other fields of military development, especially aerial and maritime. This cooperation constitutes, even nowadays, a basic and firm aspect in Israel's international alliances, as it has become evident to this date from numerous positive results which depend on the development of various models of weapons which have included rockets, PT boats, armored cars, and field guns.

At the present time, the Israeli nuclear program is based on two reactors, the first and principal one in Dimona, and the second in the district of Nahal Soreq. The available information about this new reactor indicates that it is prepared for research and development and does not possess the necessary capabilities for the production of nuclear weapons. In the Dimona reactor, however, Israel has been able to attain the necessary technology to produce heavy uranium (uranium 239) by using heavy water, which converts ordinary uranium into fissionable uranium, and doing this is the first principle in the attainment of the nuclear explosion. Furthermore, Israel also has a research center in Haifa for testing the possibility of completing the vital chemical separation in converting ordinary uranium into plutonium 239. Plutonium is considered the second fissionable substance in the world, and consequently usable as the nucleus for the fission nuclear bomb.

Israel normally obtains its supplies of uranium by using numerous secret means, the most important of which can be summarized in one word, "stealing". It has been discovered on more than one occasion that the Israeli intelligence was responsible for the seizure of cargoes of uranium in various parts of the world. The latest and most famous of these was the famous operation of the theft of the U.S. uranium in the early 1970's. This was the operation that the U.S. government denied at that time, then was obliged to admit that it had taken place, without indicating directly the role which Israel had played in the matter. Israel also gets the uranium it needs from Africa by way of the Western and South African companies which extract it from its numerous sources in the nations of Africa, especially Namibia (which is under the occupation of the forces of South Africa), Za'ire, and Malawi. Other Western sources say that the Israelis have been able to extract limited quantities of natural

uranium and then t find uranium in the Negev Desert; however, this uranium was mixed with a high proportion of phosphate, and consequently the operation of purifying it of sediment in preparation for concentrating it is considered a complex and exorbitantly costly one. This circumstance could lead the Israelis to prefer to be supplied with the material they need by way of both legitimate and illegitimate importation, and this is just what is happening now.

Military Nuclear Capability and the Probabilities of Developing It

At the present time, according to the estimate of most Western sources, Israel possesses 20 to 25 nuclear bombs. It is believed that the explosive capability of these bombs is equal to the U.S. nuclear bomb which was dropped on Hiroshima in 1945, that is to say, some 20 kilotons (one kiloton equals the effect of 1,000 tons of high explosive dynamite, and one megaton equals that of one million tons of dynamite. These two units are used in estimating the explosive force of nuclear bombs). The important factor in estimating the technical level of nuclear bombs is not only their destructive effect (for a bomb of 4 or 5 tons may be adequate to destroy a city of moderate size), but includes the size and weight of the bomb. There are three principal types of nuclear bombs, according to their size and weight. These are:

1. Primitive bombs. These are the ones whose explosive effect is related directly to their size and weight; consequently, it is not possible to develop highly effective bombs of this type without their having great weight and volume. This poses numerous difficulties in finding ways to deliver them to their targets.

2. Intermediate bombs. These are bombs with which it is possible to arrive at a reasonable intermediate solution which will combine the size and weight of two bombs for operational use on one hand and a proportional effective explosive capability on the other.

3. Compressed bombs. These are manufactured at a high technological level which provides the capability of reducing the size of the bomb without sacrificing explosive effectiveness. The countries with advanced nuclear capability, such as the U.S., the Soviet Union, Britain, and France, have arrived at the production of such bombs to equip their rockets and bombers; nevertheless, the possion of such advanced nuclear technology by other nations, including Israel itself, is still the subject of much uncertainty.

A primitive bomb with a force of 20 kilotons will have a diameter of 2 meters and weigh at least 2,000 to 3,000 kilograms (that is, about the size of a small truck); an intermediate-technology bomb with the same destructive capability will have a diameter of not more than 0.5 meter to one meter and weigh no more than 500 to 1,000 kilograms. Thus, the high-technology bomb can be transported and delivered to its target by means of numerous kinds of aircraft and rockets, and even be fired from ordinary field guns.

On the basis of this description, one can arrive at a conclusion which most Western and neutral military sources would agree on: that the "Israeli bombs" are probably of the intermediate class, and that their weight is estimated at 1,000 to 1,500 kilograms each. It is also presumable that the joint nuclear

program between South Africa and Israel is now concentrating on arriving at a technology which will be sufficient to produce compressed nuclear bombs with a high explosive capability.

The other basic factor which plays a role of major importance in determining the nuclear capabilities of one side or another is the means of delivery which that side has at its disposal and the probable specifications and effectiveness of those methods. By the term "means of delivery" is meant the land, sea, and air weapons which are capable of carrying the nuclear bombs and delivering them to their designated targets. These weapons can be fighter-bomber aircraft, the rockets which these aircraft fire, surface-to-surface rockets, rockets launched from ships or submarines, or field guns and howitzers which are capable of accommodating and firing these bombs.

By depending on his estimation of the size and weight of the Israeli bombs, the enemy will possess, if his estimates are correct, a set of weapons which are sound and capable of delivering his nuclear bombs to numerous points of the occupied Arab areas in the occupied territory. These methods include:

1. Surface-to-surface rockets. These include a number of designs, perhaps the most outstanding and significant of these being the U.S. Lance rocket. The Israeli forces obtained rockets of this design during the period from 1976 to 1977, after the U.S. approved supplying them with them in the wake of the signing of the agreement for the disengagement of the forces in Sinai in 1975. Although the Americans "stressed" at that time that the Israeli rockets (whose number was estimated at about 200 to 300) would never contain nuclear warheads, but that the delivery of them was restricted to high-explosive heads for tactical use. Israel may have, and probably does have, the capability to supply these rockets with nuclear warheads produced domestically. However, the use of Lance rockets to carry nuclear bombs remains subject to the extent of the Israeli ability to develop compressed bombs. Nevertheless, this rocket is prepared to deliver a warhead weighing 212 kilograms only. The Lance has a range of 120 kilometers and can strike its targets with precision. It is also capable of being carried and moved about on the back of an armored car.

The second most important surface-to-surface rocket in the Israeli arsenal is the medium-range rocket which is known by the name of "Jericho". The future of this rocket is still unclear to a great extent, even though numerous sources say that it is under production and in actual use. The development of it goes back to the mid-1960's, when a French company and the Israeli air industries establishment began this operation. Then the development was transferred entirely to Israel after military cooperation with it was forbidden by de Gaulle's government. The Jericho rocket, as it has become known, may constitute Israel's ideal choice to form its nuclear deterrent force. It has a range of 450 kilometers, putting a large number of cities within its reach, and with modifications it can easily carry a 500-kilogram warhead. In fact, this was done in cooperation with South Africa, and preparations are now under way to begin producing it and putting into service soon.

2. Fighter-bomber aircraft. At the present time, these are apparently the only means which has been proved capable of carrying nuclear bombs, at least overtly, for the Israeli air arm uses several types of these aircraft. Each

of these can carry bombs weighing 2,000 to 3,000 kilograms, so they can surely carry the Israeli bombs which are presumed to exist and whose weight, as we have mentioned, is 1,000 to 1,500 kilograms. The types of Israeli fighters which are capable of performing missions of nuclear bombing are the following:

The F-4 Phantom fighter, of which Israel has about 220 at the present time. Their combat range is estimated at about 1,050 kilometers, and their maximum load is 7 tons.

The A-4 Skyhawk bomber, of which Israel possesses about 250. Their combat range is estimated at 750 kilometers, and their maximum load is 3.5 tons.

The Kafir fighter, of which 120 to 130 are operating at the present time. Their range is 500 kilometers and their maximum load is about 3.5 tons of bombs and rockets.

All of these factors lead us to say that the Israeli nuclear danger is real. Only one compensation enables us to face this fact, and that is that the Arab nations are now facing the need to oppose and resist this danger as they should and must. The only way to oppose one deterrent is with another hostile and effective one. So far as this matter is concerned, many of the Arab armed forces possess the necessary means of delivery which are capable of carrying nuclear weapons, and indeed some of these means are superior in principle and specifications to those which the enemy forces possess. Suffice it for us to say here that the Arabs have for several years possessed Soviet "Scud" rockets. The Scud rocket is a surface-to-surface rocket and can carry a nuclear or conventional warhead weighing 1,000 kilograms. The Arabs also posses Frog-7 surface-to-surface rockets, whose weight is 500 kilograms. Furthermore, the Arab air arms employ a large number of MiG-27 attack fighters, whose range is 1,100 kilometers and whose attack load amounts to 4.5 tons, and Sukhoi-17's, which can carry 5 tons and whose range is estimated at about 750 kilometers. The Arabs also possess enough funds and resources to accomplish a program of nuclear development which would suffice to deter the Israeli nuclear force, saying, "Israel will never be the first to use nuclear force, and neither will it be the second!" The Arabs must make sure for their own part that they [the Israelis] in their turn are not prepared to be the first to strike such a blow as this, for they [the Arabs] will be capable of replying in kind.

CSO: 4802

ANTI-NUCLEAR GROUP ATTACKS AUTHORITIES FOR HIDING INFORMATION

Helsinki HUFVUDSTADSBLADET in Swedish 16 Jul 80 p 8

> [Text] Authorities are shutting their eyes to unpleasant facts. Nuclear plant engineers are withholding unfavorable information and the false sense of security with which IVO has lulled its employees to sleep means they cannot even be awakened by alarm signals or warning lights on the instrument panel in the control room. If nothing is done, there could be a major accident at Loviisa in two or three years!

These conclusions may be drawn from a report issued last week by the energy policy association--Alternatives to Nuclear Energy (EAK)--concerning safety at the Loviisa nuclear power plant.

The power company responded by repudiating the accusations point by point. "The EAK council of experts does not know what it is talking about," said IVO. "All is well at Loviisa I and II--or at least not bad."

Some may have been quieted by IVO's strong statement that the EAK report had been pulled out of thin air. The shock effect was further reduced somewhat when the Radiation Safety Institute guardedly sided with the Loviisa engineers.

But is that enough? We have word against word, Professor Matts Roos' against Professor Antti Vuorinen's, that of the Loviisa plant manager against that of the former Loviisa data planner who for five years had an orchestra seat at the nuclear reactor. Those who expected a debate and facts to verify the statements from the different camps have been waiting in vain the last few days. The only thing left to do is to decide in whom one chooses to believe.

There is not even agreement about such an apparently trivial detail as to how the Loviisa pressure tank is constructed. Roos states with

certainty he knows that IVO's information concerning the construction of the pressure tank is inaccurate.

It might seem farfetched to an outsider to argue about purely technical data, but the matter concerns a detail which determines whether the nuclear plant is safe or not depending upon the construction.

Matts Roos and the EAK panel of experts say that the pressure tank has a thick carbon steel wall with a rust-free alloy lining attached to the steel wall at certain points. "Hence," according to Roos and the consulting experts, "the problem is not cracks in the lining which have been given the greatest notice by Loviisa personnel." According to Roos, the danger is not associated with the cracks in the lining which would weaken the shell, but that these cracks will allow radioactive water to escape from the primary source and collect in spaces between the lining and the outer wall of the pressure tank. Water between the two different metals will create a condition similar to that in a pocket flashlight battery, an electrochemical reaction, which will drastically increase the granular border corrosion and thus quickly break down the outer wall of the pressure tank.

The mere existence of an inner lining (whose function is to protect the reactor water from soil particles in the thick carbon steel wall) thus shortens the life of the pressure tank. Matts Roos said they have the same experience in West Germany, France and the United States. According to Roos, the corrosion with the aid of electrolysis can be so heavy that cracks become critical in two to three years. Then there is the risk that the pressure tank quite simply cannot withstand the pressure and explodes.

That is according to Matts Roos and the EAK council of experts. As far as Imatran Voima is concerned, the problem is simple--it simply does not exist. Jussi Helske, the chief of operations at the plant, said there is no air and that there will be no air between the outer and the inner layer of steel. Therefore, there is no room for water either. Consequently, it would be impossible for the destructive electrochemical process described by EAK to get started at all.

"The inner layer has been welded to the outer layer with a thin bead, millimeter by millimeter, turn by turn," said Helske. "The entire surface thus formed has been melted together with the outer steel wall, forming a thickness of a few millimeters. There are absolutely no air pockets."

Samples

But the matter is not simple enough for the EAK council of experts to offhand accept Helske's assurance.

Matts Roos said:

"We believed that as late as last spring and thought the two surfaces were joined together. It was only when we had access to Imatran Voima's own material we discovered that was not the case (according to what HUFVUDSTADSBLADET has learned, the EAK managed to obtain samples which the Russians sent to Loviisa for test welding before trying to repair the cracks in the pressure tank itself. Obviously, the EAK figures these samples must be identical to the material in the pressure tank wall in order for the test welding to be meaningful at all).

"Our opinion is also supported by our knowledge of similar materials used in Sweden, West Germany and France," said Roos. "The nuclear energy commission in France reports the pressure tank wall could deteriorate in two to three years. Furthermore," Roos pointed out, "we now know that the chemical industry, for example, does not use pressure tanks constructed of two surfaces welded together; they are considered risky."

According to Roos, it is indeed possible to weld together two materials to form a surface, but, he said, "Foreign experts maintain the two surfaces will not hold together for any length of time. Because of different rates of expansion, they eventually pull apart little by little, a void develops between them and the dangerous corrosion starts."

Needle in Haystack

It is not enough that the camps are divided with respect to the development of cracks and its consequences. EAK on the one hand and SSI and IVO on the other cannot agree on whether eventual new cracks can be detected in time. EAK has dramatically let it be known that we can expect a major accident. Controls are not satisfactory, according to the EAK; each square millimeter of the huge pressure tank cannot be inspected using ultrasound, X-ray or other available methods.

"Each square millimeter can indeed be inspected," said Antti Vuorinen, head of the Radiation Safety Institute.

"In theory, yes," answered Matts Roos, "the same way you find a needle in a haystack by removing the hay, straw by straw. But," said Roos, "such pressure tank inspections would require shutting down the nuclear power plant for much of the year and that would not be acceptable for purely economic reasons."

Limits

Another example of word against word concerns the reputed excess production at Loviisa. Matti Naavasalo, a data planner who left the power company, told EAK about these excesses.

Both the Radiation Safety Institute and IVO, the last time in a TV interview with Antero Tamminen, the man closest to Anders Palmgren,

the chief of operations at Loviisa, absolutely denied there had been any excess production.

But Naavasalo told HUFVUDSTADSBLADET:

"The Radiation Safety Institute has set strict limits on the plant's operation and the reactor's output. Based on these limits, a data machine with the aid of different mathematical models continually computes the maximum output under various conditions.

"One day last March when I was on duty, one of the connecting rods dropped down unexpectedly and stopped the production in one of the fuel cells. This was recorded by the data machine, which quickly computed a new production limit for the upcoming situation. That was necessary in order to reduce the output had we continued to operate as before with one fuel cell not functioning. By maintaining the same output, there would, of course, have been increased pressure on the other cells.

"The maximum output indicated by the data machine was 1,152 megawatts," said Naavasalo. "In spite of that, the power plant ran for about an hour with an output of 1,351 megawatts. I could see that on the data screen in front of me (these figures represent heat output, not net production, which is much lower)."

"Naavasalo interpreted the situation incorrectly," according to the Radiation Safety Institute. "The plant was running a test program and did not take all circumstances into consideration."

"Impossible," said Naavasalo. "It was an old program, a program we had been running for months, maybe a year prior to that."

Beyond Its Goal

EAK and IVO are not only arguing about production excesses and the construction of the pressure tank. Matts Roos and his council of experts have compiled a whole list of altogether 12 complaints against the Loviisa power plants. But the two examples mentioned above perhaps best show the glaring differences between the parties.

Of course, IVO repudiates the other accusations with equal determination. On some points it seems obvious that the EAK has aimed well beyond its goal. With respect to other points it is a matter of philosophy. Both sides recognize the facts in the matter, but draw different conclusions and judge the risks differently.

The fact that the report contains formulations that show the EAK council of experts, at least in some instances, talks about things it knows nothing about does not embarrass scientist Matts Roos. He in part

refers to EAK's problem in getting relevant information. IVO does not provide any information at all and the Radiation Safety Institute does not seem to be able to disclose technical details which IVO has chosen to regard as business secrets. According to Roos, incorrect details against this background will not affect EAK's credibility. Little mistakes on some points will be compensated for by EAK's rightness in other matters.

Matts Roos said:

"Earlier we tried to establish some kind of an international council of experts which would also have included critics whom we would have consulted, a kind of 'hearings' American style. However, the politicians we talked to said this could not be done here; politicians would never go along with it because it would be considered an acknowledgement of their own incompetence. For a time we gave up the idea, but now it seems that such hearings would be the only way to get accurate information about many basic questions.

The truth must be known. And I would like to advocate such hearings so as to determine for myself whether it would help to call in neutral foreign experts and get their opinions," said Roos.

"Malice"

Matti Naavasalo, who today works for a company in northern Finland, is no less interested than Roos in having EAK's accusations subjected to a thorough investigation. His part of the report primarily concerns production excesses as well as other bits of information and the company's repudiation came as a shock to him.

"All of my information should be documented in IVO's files," said Naavasalo, "and it should be aired or I will appear to have given false witness against my former employer.

"On the other hand," said Naavasalo, "the company management has told half truths or been reluctant to express itself at all on previous occasions when the situation was critical."

Naavasalo gave an example:

"Following last year's audit when the plant was again put into operation, one of the data experts discovered that something was wrong inside the reactor. The plant was quickly shut down again and the defect was discovered, a connecting rod which regulated the power output was not functioning because it was stuck. After adjusting the connecting rod, the plant was started up again and all went according to plans."

The management did not publicize this episode; plant employees were not even told what had happened, according to Naavasalo. The delay was routinely explained as "Some last-minute work that had to be done before the reactor could be started up again."

"The incident was not that dramatic," said Naavasalo, "but it did reveal a great deal about IVO's attitude as far as its handling of facts is concerned."

IVO's commentary:

"A malicious statement. We do inform plant personnel when we have the opportunity. We have always done that."

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CSO: 5100

GOVERNMENT POLICY ON NUCLEAR WASTE MANAGEMENT, RECYCLING

Duesseldorf ATOMWIRTSCHAFT-ATOMTECHNIK in German Jun 80 pp 294-299

[Article by Chief of Division Dr W. J. Schmidt-Kuester, head of Department of Energy, Environment, and Raw Materials of the Federal Ministry for Research and Technology: "The Waste-Disposal Plan of the Federal Government." Survey paper read at the annual conference of the German Atomic Energy Forum and the Nuclear Engineering Association on 25-27 March 1980 in Berlin]

[Excerpts] The new waste-disposal framework is based on the waste-disposal principles adopted on 29 February 1980 by the government leaders of the Federal Government and Laender, and it replaces the former nuclear waste-disposal center with the concept of the integrated waste-disposal plan. What is understood by this is a closed system for the intermediate storage of depleted fuel assemblies, their reprocessing or treatment, and the conditioning and ultimate storage of the wastes. Despite the altered time frame for the realization of the waste-disposal plan, these waste-disposal principles still allow a tolerable waste-disposal certification for the nuclear power plants under construction and operating in the FRG. At the same time, by a spacing out in time of the sharpening of the requirements on the waste-disposal certification, these principles should be conducive to the speedy materialization of waste-disposal facilities.

The Waste-Disposal Plan of the Federal Government

The resolution of the government leaders replaces the nuclear waste-disposal center with the concept of the integrated waste-disposal plan. What is understood by this is a closed system for the intermediate storage of spent fuel assemblies, their reprocessing or treatment, and the conditioning and ultimate storage of the wastes.

The fixed building blocks of this resolution are:

- the intermediate storage of spent fuel assemblies, inclusive of their storage in solid-waste storage facilities;

- the optimization, in terms of safety, of reprocessing techniques;

- the concurrent investigation of other waste-disposal techniques, with the objective of acquiring sufficient information so that by the middle of the 1980's at the latest a decision can be made on whether decisive safety advantages could be gained from these techniques;

- the speedy exploration and development by mining operations of the salt dome in Gorleben;

- confirming in essence the "principles on waste-disposal provisions for nuclear power plants" and giving orders for adapting the details of these principles so as to correspond to the changes in the waste-disposal plan.

These individual "building blocks" will be considered somewhat more closely in what follows. As it happens, in certain areas there has been quite important progress within the last 12 months, which is pushing into the background already the memory of the low point reached for nuclear energy development as a whole which was represented by the decision of the Lower Saxony Land government of 16 May 1979. Especially if one includes in this progress the proposal for a small reprocessing facility in Hesse, for which also a licensing procedure is going to be conducted truly in earnest, in contrast to the Lower Saxony case.

Intermediate Storage

There was agreement among the government leaders that for a transitional period our intermediate-storage possibilities must be expanded. The readiness of the Land governments of North Rhine-Westphalia and Lower Saxony to accommodate an off-site intermediate-storage facility is welcomed. The construction of other off-site intermediate-storage facilities may become necessary sometime in the 1990's.

The resolution of the government leaders assumes that up to and including 1985, all fuel assemblies from German nuclear power plants--that is, around 2,100 tons of uranium--will be taken for reprocessing to the French reprocessing facility near Cap de la Hague, on the basis of agreements already concluded, that solid-waste storage facilities will be established in most of the existing nuclear power plants and in all new plants, and that the putting into service of off-site intermediate-storage facilities with a capacity of 1,500 tons of uranium each will be necessary in the years 1985, 1994, and 1997. A time leeway of 2 years is contained in these figures.

The assumption with respect to solid-waste storage is beyond doubt by now. Early in February 1980, the Federal Government agreed in principle to the establishment of solid-waste storage facilities. Meanwhile, the

Hessian Land government has granted a license for the initial operation of the solid-waste storage facility at the nuclear power plants Biblis A and Biblis B, on the basis of a corresponding directive by the Federal Minister of the Interior.

A significant advance in the sector of intermediate storage is represented by the development of intermediate storage by shipping casks. This is the result of joint research work by the DWK [German Company for Reprocessing Nuclear Fuels] and STEAG [Hard-coal Electricity, AG]. This storage in shipping casks must be characterized as an especially safe kind of intermediate storage ecologically speaking, since no radioactive emissions are released to the environment from such an intermediate store of spent fuel assemblies. Also, by using this concept the radiation exposure to the employees is likely to be markedly below the radiation exposure in connection with using liquid storage. In light of the advantages of storage in shipping casks, an application was filed by the DWK in October 1979 for the establishment of a shipping-cask storage facility for the site of Ahaus in North Rhine-Westphalia. This application is to be processed on a priority basis, before the licensing procedure still in progress for the construction of a liquid-storage facility.

In Lower Saxony as well, the establishment of an intermediate storage facility is also making progress. On 5 March 1979, the kreis assembly of Luechow-Dannenberg delivered a positive ruling on the accommodating of an intermediate-storage facility in this rural kreis. It can be assumed for this that the Lower Saxony Land government will thereupon be naming a site in this rural kreis for the construction of an intermediate-storage facility. It is encouraging to observe that in the sector of intermediate storage, the search for sites is no longer based on "passing the buck" but is increasingly influenced by the modest beginnings of the competition principle and utilitarian considerations.

Reprocessing

On reprocessing, there was agreement among the government leaders of the Federal Government and Laender that this technique--with recycling of the unused nuclear fuels and ultimate storage of the reprocessing wastes--can be realized in a safe way on the basis of the present level of science and technology, and that the necessary waste disposal of the nuclear power plants is ensured both from the standpoint of ecology and also from that of economy. The key words "economy" and "ecology" are especially important in this connection.

Used-up fuel assemblies are not "radioactive ash," and they are not "nuclear waste." Following their use in the nuclear power plant, the fuel rods still have the following contents:

95 percent of the uranium originally contained in them, which can be used again, and

1 percent of newly generated plutonium, as well as

4 percent of fission products, the wastes proper of nuclear fission.

That is, 96 percent of the materials contained in the used-up fuel assemblies can be recovered by reprocessing and can be used again as fuel. To me, so far there is no other case known which can come even close to reaching such an efficiency of raw-material recovery.

From this efficiency of recycling nuclear fuels by reprocessing, energy-saving and economic advantages result which we should not do without in view of the world energy situation, and which we also must not do without in light of the energy needs of the Third and Fourth Worlds. The following figures make this clear:

- The amount of power-producing raw materials which can be recovered in a plant with an annual capacity of 1,400 tons corresponds to 40 million tons of SKE (hard coal units) if the recovered nuclear fuels are employed in light-water reactors. A single pit is needed for the ultimate storage of the fission products separated out in this recovery. For the extraction of the same amount of hard coal, at least 12 large hard-coal mines are necessary. The investment costs for the creation of these hard-coal mines are of the same magnitude as the estimated investment costs for the construction of the nuclear-waste disposal center. From the standpoint of the condition of the countryside, it could be remarked also in connection with this comparison that for each of these hard-coal mines a large pit heap is thrown up in the course of the time period they are worked, whereas the salt dome in Gorleben is largely transferred back again into the mining pit in the course of operation.

- The employment in fast breeders of the nuclear fuels recoverable annually by reprocessing in a plant with a capacity of 1,400 tons per year would make available an energy potential of around 2.4 billion tons of SKE per year. This figure alone makes clear the energy-policy significance of reprocessing and breeders.

But reprocessing also brings decisive ecological advantages as well:

- Through the recycling of the recoverable uranium and the newly generated plutonium in light-water nuclear power plants, the resulting amount of plutonium is drastically reduced, and by its concurrent utilization for power generation the amount of radioactivity is decreased to some extent. It is better to burn plutonium in light-water reactors than to put it in ultimate storage as spent fuel assemblies and to create in this way "plutonium mines" in the course of time.

- The separation of the recoverable nuclear fuels by way of reprocessing ensures a safe ultimate storage of the radioactive wastes, because the fission products can be separated out and, depending on their differing properties, can be conditioned and safely put in ultimate storage.

For the further development of reprocessing techniques, the resolution of 28 September 1979 argues that work must be done towards this end so that a reprocessing facility can be constructed as speedily as possible, taking into consideration all aspects of the problem in question. The objective of this further development is optimization in terms of safety. Besides our carrying on with the research and development work, above all our continuing the operation of the reprocessing facility in Karlsruhe, in this connection we also attach exceptional significance to the initiative of the Hesse Land government with respect to a site for a small reprocessing facility in the Land of Hesse. The Hessian State legislature took up this initiative on 28 February 1980 and adopted a motion of urgency by the SPD and FDP factions in which it seconds the readiness of the Land government "to help in solving the problems of the reprocessing of spent fuel assemblies and to include Hesse as a possible site for a reprocessing facility." This is proof that the disposal of wastes from nuclear power plants through reprocessing is "politically feasible" in the FRG. With this, the Hessian State legislature and Land government are displaying courage on the subject of waste disposal, which may be decisive for the energy supply of the FRG over the long run. Thus they are in agreement with the resolution of the government leaders of the Federal Government and Laender on constructing a reprocessing facility as speedily as possible.

Other Waste-disposal Technologies

The resolution of the government leaders of the Federal Government and Laender of 28 September 1979 on the disposal of the wastes of nuclear power plants also provides for the investigation of other disposal technologies--such as, for example, the immediate ultimate storage of spent fuel assemblies--with respect to their realizability and the assessment of their safety. These investigations are to be carried out speedily so as to make it possible to come to a definite decision by the middle of the 1980's at the latest on whether safety-related advantages can result from these other techniques.

Under the leadership of the Karlsruhe Nuclear Research Center and with the assistance of roughly 10 different agencies in industry and research, a stocktaking is being conducted at present on the international status of other waste-disposal techniques as well as an initial comparison between these waste-disposal technologies and the integrated waste-disposal plan. Initial procedural considerations for the technical realization of the other disposal techniques have been included in this investigation. On the basis of these considerations, proposals for further development

are being worked out. The results of this study will be known by the middle of 1983. The continuing investigations will then be initiated immediately. We will do everything we can to move forward rapidly on these investigations and developments, so that by the midule of the 1980's at the latest, but earlier if possible, the comparison can finally be made between the other disposal techniques and the integrated disposal plan, as requested by the government leaders.

The heads of government of the Federal Government and Laender have assigned to the Federal Government/Laender Committee for Nuclear Power the task of supervising the work on optimization in terms of safety of the reprocessing process and the work on the other waste-disposal techniques. Thus the know-how and experience of the nuclear-power licensing authorities of the Laender is to be taken into account in the further development of waste-disposal possibilities. Owing to the introduction of a licensing procedure for a small reprocessing facility in Hesse, in my opinion the Federal Government/Laender Committee is taking on importance above all relative to its task of comparing the different disposal techniques, whereas its function with respect to further safety-related optimization of reprocessing technology is quite likely to be superseded to a very great extent.

Exploring and Development of an Ultimate Storage Area

The exploring and development by mining operations of the salt dome in Gorleben is to be pushed forward speedily on the basis of the resolution of 28 September 1979, so that the information needed for the requisite decisions on the salt dome can be known within the second half of the 1980's.

In this area, encouraging progress can be noted. The deep drillings which are important for the exploration of the salt dome have begun. By now, the first drilling has reached a depth of 850 meters (level on 9 March 1980). The drilling site for the second deep drilling has been prepared. Further drillings are to follow immediately.

The hydrogeological drilling program is running essentially on schedule, if one disregards legal brawls on the right-of-way for the sites and the accidental destruction of one drilling hole.

Finally, the founding of the German Company for the Construction and Operation of Ultimate Storage Facilities for Radioactive Wastes (DBE) is an important advance in this sector. The DBE will help the PTB [Federal Physico-technical Institute] in planning and carrying out further deep drillings as well as in the planning and materialization of the ultimate-storage pit.

Waste-Disposal Principles

On 28 September 1979, the government heads of the Federal Government and Laender directed the Federal Government/Laender Committee for Nuclear

power to make adaptations of the waste-disposal principles in accordance with the resolution. This adaptation process has proved to be more protracted and difficult than had originally been assumed. In the end, it was necessary to allow to the plants now under construction and in operation a tolerable and quantifiable waste-disposal certification, despite the altered time frame for the materialization of the disposal plan, and on the other hand to work toward the timely and rapid materialization of waste-disposal facilities by means of a spacing out in time of the sharpening of the requirements on the waste-disposal certification. The waste-disposal principles adopted by the government leaders of the Federal Government and Laender on 29 February 1980 require, for purposes of basing the waste-disposal certification on the integrated disposal plan:

- the preselection of one or several basically suitable sites for an off-site intermediate storage facility--unless an intermediate storage has been ensured at the site of the nuclear power plant--or for a reprocessing facility;

- a positive assessment by the RSK [Reactor Safety Commission] and SSK [expansion unknown] of the basic realizability in terms of safety of the intermedia e storage of irradiated fuel assemblies in off-site intermediate storage facilities, for a period of time of at least 20 years;

- continuation of the current plan-assessment procedure, as well as progress in the exploration and development of an ultimate storage facility;

- the granting of initial interim construction permits and of interim operating licenses from 1 January 1985 on only if in addition to the above-mentioned prerequisites, progress has been made in the construction of one or more reprocessing facilities or one or more facilities for the treatment of irradiated fuel assemblies for ultimate storage without reprocessing. At the least, the preselection of a site for one of these facilities must be made. As to nuclear power plants for which there was an initial interim construction permit on 28 September 1979, this regulation is to be effective from 1 January 1986 on.

I would like to conclude my comments on the waste-disposal plan of the Federal Government with the observation that by this means the disposal of wastes by German nuclear power plants is technically realizable and can be done in a responsible way from a safety standpoint. This waste-disposal plan should be viewed as a plan which gives the framework, in terms of time periods and content, for the realization of nuclear waste disposal in the FRG. In the future, it is essential for all responsible parties to strive to fill in this framework plan. As long as this demonstrably happens and moreover progress is achieved as well--progress which is not jeopardized again by influences of one-sidedly

oriented groups or by political intrigues--I am optimistic about the continued future of nuclear energy in our country.

Ultimate Storage of Weakly Radioactive Wastes

In a survey on the status of our waste disposal system, we must also examine the removal of the weakly radioactive wastes now accumulating at the Land collection points, the research centers, and at the nuclear power plants. Up to the end of 1978, it was possible to store these wastes in the Asse, in connection with large-scale experiments done there. According to Section 3 of the Radiation Protection Regulation, the necessary license to do this expired on 31 December 1978. On the basis of the Fourth Amendment to the Atomic Energy Law, in its place the conducting of a plan-assessment procedure was required for the ultimate storage of these wastes. But since the conducting of a plan-assessment procedure takes several years, as an interim measure we investigated the possibility of a retrievable intermediate storage in the Asse area, which could be done according to Section 3 of the Radiation Protection Regulation. However, within the framework of the licensing procedure for this purpose which was in effect since the end of April 1979, meanwhile substantial though quite comprehensible stipulations were made, which require that:

1. At the beginning of such a storing, all mining work in unfamiliar field sections of the Asse are to be suspended. But unfamiliar field sections of the Asse must continue to be explored, in order to prepare for further phases of this retrievable intermediate storage and to locate the saddle core of the salt dome and develop it for the purpose of conducting a great number of investigations and researches which are indispensable to the licensing of the ultimate storage area in Gorleben. 2. In case retrieval is necessary, the whereabouts of the wastes must be verified. The realization of this requirement may lead to the paradoxical-sounding possibility that the weakly radioactive wastes will be put in intermediate storage in a complicated and expensive way in the Asse salt dome, whereas above the ground completely functional storage rooms for intermediate storage are standing empty.

The above-mentioned stipulations lead to the conclusion that the further pursuit of this plan of retrievable intermediate storage probably has no prospects for success. In all probability, we will have to abandon this plan. A comprehensive plan-assessment procedure both for the ultimate storage of weakly radioactive wastes and also for research and development studies with radioactive materials which remain in the Asse will be introduced immediately. Until the completion of this plan-assessment procedure, the accumulating radioactive materials are to be put in intermediate storage in the Land depots, at the research centers, and at the nuclear power plants.

The Asse mine pit has only a limited capacity. Therefore in connection with long-range planning for the disposal of weakly radioactive wastes it should also be considered whether the capacity of the Asse is a sufficient supplement to the ultimate storage area in Gorleben. In order to be certain, preparations should be made for an additional ultimate storage area. In this connection it is reassuring to hear that suitability investigations on the Konrad mine pit are not only making good progress, but are also bringing very promising results.

At present, the Federal Government is on the point of developing a plan for the long-range disposal of weakly radioactive wastes, with due regard being given to the results and experiences now at hand. This plan is based on the above-mentioned considerations, and it could be adopted by a resolution of the government leaders of the Federal Government and Laender in the summer of 1980.

Final Remarks

With this paper, a survey was to be given on the state of development of the German waste-disposal plan. The Federal government will do its rightful part for the realization of this plan. It is important that all the other parties having joint responsibility in this sector contribute their share also, in order to ensure that nuclear energy can really play the role appropriate to it within the framework of our energy policy.

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STATUS OF ATOMIC URANIUM LASER ISOTOPE SEPARATION RESEARCH

Milan ENERGIA NUCLEARE in English Mar 80 pp 151-156

[Text]

INTRODUCTION

In the past decade the Laser Isotope Separation (LIS) techniques have arisen an increasing large interest, specially in the uranium enrichment area. This falls into a more general interest for the development of new uranium enrichment processes economically competitive with the existing industrial processes, based on gaseous diffusion and ultracentrifugation methods. As is well known, such processes are a very expensive stage of the conventional nuclear fuel cycle, specially from the capital investment point of view. As regards Laser Isotope Separation, it can potentially reduce capital costs by 80% [1], while being competitive for the operating costs.

Currently several LIS processes are being investigated. They can be subdivided into two classes differing only as for the feeding material, which may be atomic uranium or one of its molecular compounds with convenient vapour pressure (usually UF_6). This paper is aimed at introducing the basic principles referring to atomic uranium LIS methods.

THE ISOTOPIC SHIFT AND THE SELECTIVE STEP

Feasibility of any LIS technique requires the existence - in the atomic optical spectrum of the isotope to be separated - of the «isotopic shift» in the corresponding electronic levels [2]. In other words, at least one transition between the same electronic levels must occur at different energies for different isotopes of the same atom (see the first transition in fig. 1).

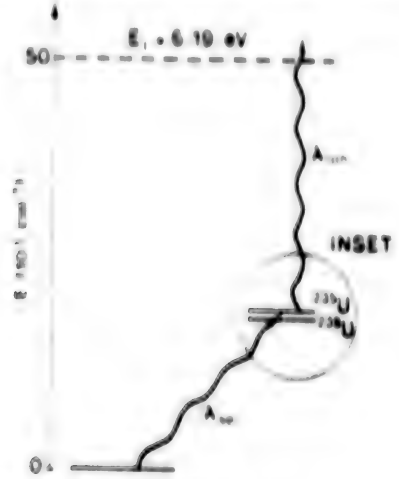

Fig. 1 - Spectroscopic transitions for the uranium isotopes.

In isotopes, such a shift is due to a different nuclear setting that, by a mass and/or volume effects influences the energy of the electronic levels. In the case of heavy atoms like uranium, only the volume effect practically originates the isotopic shift.

For photoseparation purpose, the shift can be exploited as follows. First of all, a sufficiently monochromatic radiation shining an isotopic mixture excites only one isotopic species; thus differentiated from the others, this species can be subsequently processed and separated from the mixture: for instance, as illustrated in fig. 1, a second photon flux having an adequate $h\nu$ can ionize only the (selectively) excited isotope.

Therefore in a LIS process the following conditions must be fulfilled

1 Existence in the absorption spectrum of the desired isotope of at least one transition at frequency ν, not overlapping the absorption transitions of the other isotopes

2 Availability of an optical source at frequency ν, with adequate monochromaticity and intensity (selective radiation)

3 Existence of a physical and/or chemical process suitable to perform the transformation and separation of the excited species only

4 Preservation of the selectivity achieved in the first step during the whole process

Strictly speaking, none of the conditions quoted above involves the use of laser radiation and, as a matter of fact, in certain cases - for instance in the case of Hg - the isotope separation has been achieved also with a conventional optical source. In these cases, a passive filtering in the frequency domain was performed to such an extent as to obtain optical selectivity, if necessary regardless of any economical yield.

On the contrary, in a dye laser the filtering can be active, for instance using a grating coupled with an FP etalon: moreover, the collimated laser beams allow high irradiances over long absorbing paths. Therefore the lasers development has re-proposed the suitability of the photo-assisted isotope separation not only for a larger number of atomic elements but also for industrial applications.

TWO-STEP SELECTIVE PHOTOIONIZATION

As it will be detailed later on, several physical processes can be utilized for the stabilization and separation of selectively excited species. In the simplest case, already described in fig. 1, the mixture is irradiated with a second photon flux which is not isotopically selective but is able to ionize only the excited species. This technique is called « two-step selective ionization ». Of course the second photon flux energy must fulfil the two requirements.

$$\frac{h\,c}{\lambda_{ionis}} < E_{ionis}$$

$$h\,c\left(\frac{1}{\lambda_{sel}} + \frac{1}{\lambda_{ionis}}\right) \geq E_{ionis}$$

A laboratory experimental set-up preliminarily used by the authors for a two-step ionization process and for diagnostics studies only is shown in fig. 2. The radiation coming from a 10 ns N_2 laser is divided into two fractions: the smaller one pumps a narrowband tunable dye laser, which in its turn supplies the selective radiation ν_{sel}, while the larger fraction constitutes the ionizing photon flux, ν_{ionis}.

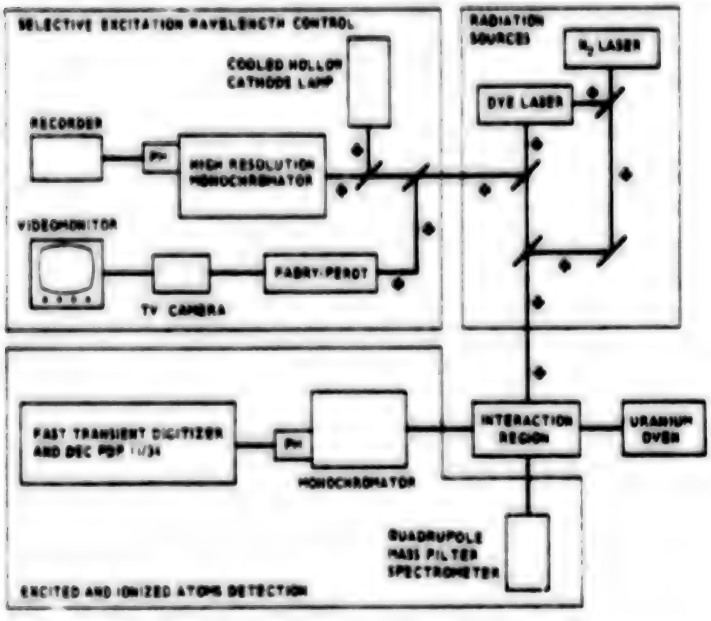

Fig. 2 - Schematic layout of the experimental system.

A suitable optical system, partially shown in fig. 2, allows for the two beam mixing and focalization in the interaction region. The correct timing sequence ($\nu_{sel} \rightarrow \nu_{ionis}$) is achieved by optical delay on the ionizing beam.

In order to reduce the Doppler width of the absorption lineshape, the atomic uranium vapour is passed through a couple of slits and reaches the interaction region as a well-collimated beam perpendicular to the direction of the combined optical beams.

The uranium vapour is obtained by electron gun bombardment: the evaporating uranium temperature is roughly 2 400 K and the vacuum in the interaction chamber is better than 10^{-7} torr.

A monochromator and a quadrupole mass filter

analyser are disposed perpendicularly to both laser and vapour beams. The monochromator analyses in time and wavelength the fluorescence emitted from the selectively excited levels, while the quadrupole mass spectrometer counts the ionized atoms. The non selective ions coming from the oven are deflected and captured by means of an electric field before they can reach the interaction region.

The separation effectiveness depends – among others – on the selectivity obtained in the first step, therefore particular attention must be given to the isotopically selective transition characteristics. Consequently an apparatus is required for measuring and controlling both wavelength and linewidth of the dye laser radiation. The first goal is accomplished by means of a high resolution ($R \simeq 3 \cdot 10^6$) monochromator and using, as a reference spectrum, a hollow cathode lamp, loaded with enriched uranium and water or liquid nitrogen cooled.

The spectral width and jitter of the dye laser radiation can be controlled by means of a Fabry-Perot interferometer, whose interference fringes are monitored by a vidicon.

LASER REQUIRED FEATURES

All the LIS techniques achieve selectivity at least in the first step, but they differ in the process used for stabilizing and separating the excited isotopes. In the case of atomic uranium, the most convenient process seems to be ionization, since ions are separated from the atomic vapour by electric and or magnetic fields. Ionization can be achieved through a different number of steps; the processes currently more investigated are shown in fig. 3 [3, 4]. These multistep processes differ from the one described in fig. 2, in that the last step exploits the absorption cross section increase occurring when – instead of using transitions to the continuum – the atom is brought to an upper bound state which is just below the continuum spectral threshold (high-lying Rydberg levels), or to a mixed configuration, still bound but ionizing (autoionizing levels). In the former case just an IR photon or an electric field are required to complete the photoionization; in the latter case, the system spontaneously evolves towards ionization. The absorption cross section value for the Rydberg or autoionizing levels may

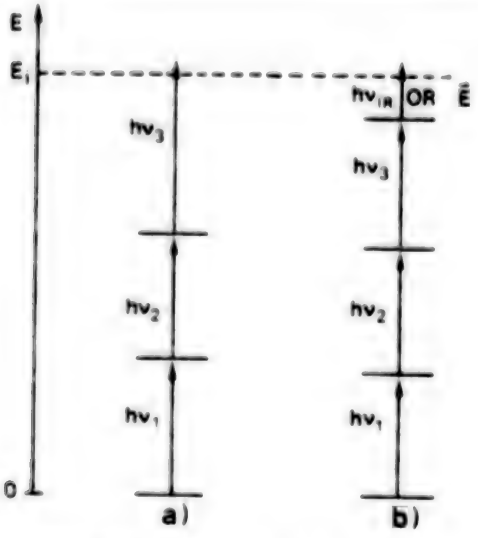

Fig. 3 - The processes currently more investigated:
a) Three steps with autoionization
b) Three steps towards a Rydberg state and subsequent ionization with electric field or IR photon.

be $1 \cdot 10^{-16} \div 10^{-15}$ cm², instead of $1 \cdot 10^{-17}$ cm² or less for a crude ionization.

According to the current laser technology, processes with more than two steps are required for the following reasons. The major drawback of the atomic uranium process being the atomization energy, all atomized uranium must be irradiated; furthermore, in a hypothetic enrichment module, atoms would leave the molten metal continuously, with a speed around 450 m s^{-1}. Consequently, CW lasers or pulsed lasers having a repetition rate of about 10 kHz are needed to shine every single atom.

The current CW visible lasers are not economic, while, among the pulsed lasers, the copper vapour laser (CVL) seems to be a good candidate, since it can work at a pulse repetition rate higher than 10 kHz, with efficiency $\cong 1\%$; but, since the lasing wavelengths are 510 and 578 nm, the resulting tunable dye laser CVL pumped can lase at $\lambda \geq 550$ nm, corresponding to an energy around 2 eV. In conclusion, it is not possible to reach the 6.2 eV uranium ionization using two steps only. In this context other efficient laser sources are under study, specially the excimers lasers emitting radiation at shorter wavelength. Also the resort to Rydberg or autoionizing states, and consequently to a tunable laser, is only an apparent complication. In fact, a simple approach shows that, to efficiently exploit the selectively excited atoms, the following relation holds between the irradiances I (photons · cm^{-2} · s^{-1}) of the ionizing step and the preceding one

$$\frac{I_{\text{ioniz}}}{I_{\text{ioniz}-1}} \simeq \frac{\sigma_{\text{ioniz}-1}}{\sigma_{\text{ioniz}}}$$

where σ is the absorption cross section. If the ionizing step involves a non-bound state, it has $\cong 1 \cdot 10^{-17} \div 10^{-18}$ cm², while the preceding step has $\sigma \cong 10^{-16}$ cm²; consequently, I_{ioniz} is 10^2 to 1^3 times the irradiance of the preceding step, and a large amount of photons is wasted.

On the contrary, $I_{\text{ioniz}} \to I_{\text{ioniz}-1}$ if a suitable bound state is selected.

SPECTROSCOPIC REQUIREMENTS

In the design of a LIS process, the choice of the spectroscopic transition is important, particularly of the selective one or ones. A useful screening through such a complex spectrum as that of uranium (1 500 assigned levels, 90 000 observed transitions from the near UV to the near IR [5]) can be supplied by the following criteria fulfilment:

i) isotopic shift larger than the absorption linewidth, to achieve a high excitation selectivity;

ii) large absorption cross sections, for a better process efficiency;

iii) sufficiently long lifetime τ_{level} of the excited levels, to allow the subsequent laser pulse to work on the largest available excited atomic population;

iv) laser pulse length $\leq \tau_{\text{level}}$ for the reason explained later on.

As for condition i), it should be kept in mind that the absorption lineshapes of the ^{235}U show an hyperfine structure, due to a non-zero nuclear spin moment ($\bar{I}_{235} = 7/2$ while $\bar{I}_{238} = 0$) [6].

Of course the knowledge of other spectroscopic parameters may be useful or necessary in setting up a LIS process; some of them are shown in fig. 4. In the unclassified scientific literature there is a lack of information regarding specially the intermediate, Rydberg and autoionizing levels, so that a rather extensive preliminary spectroscopic research is needed in view of a possible industrial application of a LIS process.

LOSS OF SELECTIVITY

Some processes tend to reduce the efficiency of a LIS technique: more precisely, it is possible to distinguish between two different kinds of processes:

a) loss of selectivity

b) waste of atoms and/or photons.

The energy and charge transfer belong to the first kind of losses. As a matter of fact, whatever ^{235}U

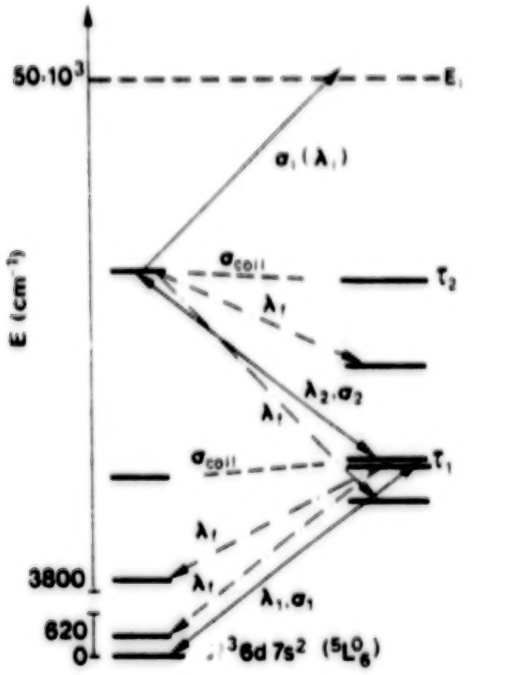

Fig. 4 - Spectroscopic parameters of a LIS process.
——— Excitation and resonant fluorescence.
—·—·—·— Fluorescence.
– – – – – – Energy transfer by collisions.

excited level may exchange its energy with an atom of the more abundant ^{238}U via a quasi-resonant collisional mechanism, thus vanishing the work spent by the laser radiation. Still, the ion $^{235}U^+$ may collisionally transfer its own charge, missing in this way its separation chance, unless conditions of charge but not moment transfer occur.

Such problems can be overcome by accurately selecting the experimental conditions: for instance, the atomic vapour density should not exceed $1 \cdot 10^{14}$ atoms $\cdot$ cm^{-3} [7].

The second kind of losses depends on the uranium complex spectrum: among other, the following causes are to be mentioned.

1. Thermal population of spectroscopic levels

As it is well known from the Boltzmann's law, the atomic energy levels are populated according to system temperature and level energy, number and degeneration. In other words, to determine the real population of a defined level, the partition function must be taken into account. The presence of low-lying energy levels in the uranium spectrum, together with the high temperature needed for a beam of a suitable density, implies that less than 50% of the atoms are in the fundamental level and can undergo the laser excitation. The system efficiency can be increased by adding a further selective laser wavelength operating on the 620 cm^{-1} level, which contains about 30% of the atoms.

2. Hyperfine structure

Another complication in the ^{235}U spectrum has been already mentioned, namely that given by the hyperfine structure of the spectroscopic levels which causes an hyperfine pattern in the absorption profile. Of course, to minimize the selectivity losses only the transitions with a hyperfine envelope smaller than the isotopic shift may be selected. Nevertheless, the photon's frequencies falling into the «holes» of the hyperfine pattern are lost if a proper inhomogeneous broadening cannot be applied.

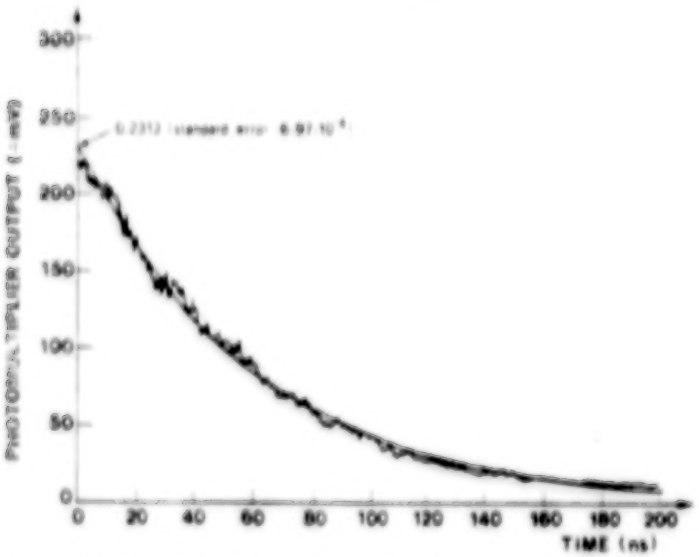

Fig. 5 - Fluorescence decay curve. Level lifetime, $5.93 \cdot 10^{-8}$ s (standard error, $2 \cdot 10^{-10}$ s).

3. Metastable levels with $E < h\nu_{sel}$

These levels, usually of the same parity as the fundamental one, radiatively depopulate the selectively excited level. Such decays ruin the effect of the selective radiation and are definite losses of ^{235}U, since the collisional deexcitation lifetimes of metastable levels are in general longer than the atomic transit time in the interaction region. For this reason, the lifetime of the excited level should be longer than the laser pulselength and the pulses have to be synchronized.

Moreover, the metastable levels are potentially the lower level of an unwanted laser action when a population inversion is established with the upper, selectively excited level.

EXPERIMENTAL RESULTS

Some experimental results obtained at Laboratorio Tecnologie Speciali of CNEN, CSN-Casaccia, are shown in fig. 5 and at the end of this section. As above mentioned, the lifetime of the U levels is obtained by monitoring the fluorescence decay curve after laser excitation (see also fig. 2).

The photomultiplier output is sent into a Tektronix Transient Digitizer which accumulates the photoelectron time distribution every laser pulse. After a suitable number of pulses, it is possible to obtain the decay curve, which is processed by a DEC-PDP 11/34 coupled with the digitizer.

The transition here considered is between the fundamental level $5f^3\,6d\,7s^2\,(^4I_{\frac{9}{2}}^o)$ and a level $J=6$ at 22 754.058 cm^{-1}; the lifetime reported elsewhere [8] is in agreement with our experiment.

The ionization data obtained with the apparatus described in fig. 2, tuned on ^{235}U and involving, as a first step, the same mentioned transition, are here reported:

	$\lambda_{sel} + \lambda_{ionis}$	λ_{sel} only	λ_{ionis} only
Number of ion counts	10 700	2	80

Manuscript received February 5, 1980

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BRIEFS

AGAINST NUCLEAR ENERGY--The Hague, July 22--More than one-third of the Dutch population is opposed to any new nuclear power plants being built in the Netherlands, according to a public opinion poll published today. A similar number also want the country's one commercial nuclear reactor to be closed down as soon as possible, the Netherlands Statistics Foundation said. It conducted the poll among 980 Dutch people in June. Thirty-six percent were against new nuclear stations even though future energy supplies might be threatened if they were not built. Some 49 percent said the present reactor at Borssele should remain in operation but that no new plants should be built until the problems of nuclear safety and waste disposal are solved. The government last week launched a national debate on the future of atomic energy by proposing the construction of another three nuclear power stations. A white paper presented to parliament said considerable expansion in the use of nuclear energy was necessary to make the country less dependent on imported coal and oil. [Text] [The Hague ANP in English 23 Jul 80 p 1]

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